

# Some Issues In W/Z Physics

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W/Z events for QCD studies

QCD effects on W/Z events

- Soft/hard interface
  - event shapes
  - colour coherence
  - a new event shape for hadron-hadron collisions
    - Banfi, Marchesini, Smye & Zanderighi  
hep-ph/0106278
    - "non-global" logarithms
      - Dasgupta & Salam  
JHEP 0203:017
      - JHEP 0208:032
    - Appleby & Seymour  
JHEP 0212:063
- W+n jet simulation
  - multijet matrix element + parton shower matching
    - Richardson et al

Reorganize ("resum") large logs by exponentiation:

$$1 - \alpha_s L^2 + \alpha_s^2 L^4 - \alpha_s^3 L^6 + \dots \sim e^{-\alpha_s L^2} \quad (\text{Sudakov})$$

(DLA)

but large logs are still present:

$$\ln(\Sigma(T)) \sim \boxed{-\alpha_s L^2 + \alpha_s^2 L^3 + \alpha_s^3 L^4 + \alpha_s^4 L^5 + \dots} \quad (\text{LLA})$$
$$+ \alpha_s L + \alpha_s^2 L^2 + \alpha_s^3 L^3 + \alpha_s^4 L^4 + \dots \quad (\text{NLLA})$$

+ : + : + : + :  
exact state-of-the-art

can also resum these:

$$\ln(\Sigma(T)) \sim L f(\alpha_s L) + g(\alpha_s L) + \dots$$

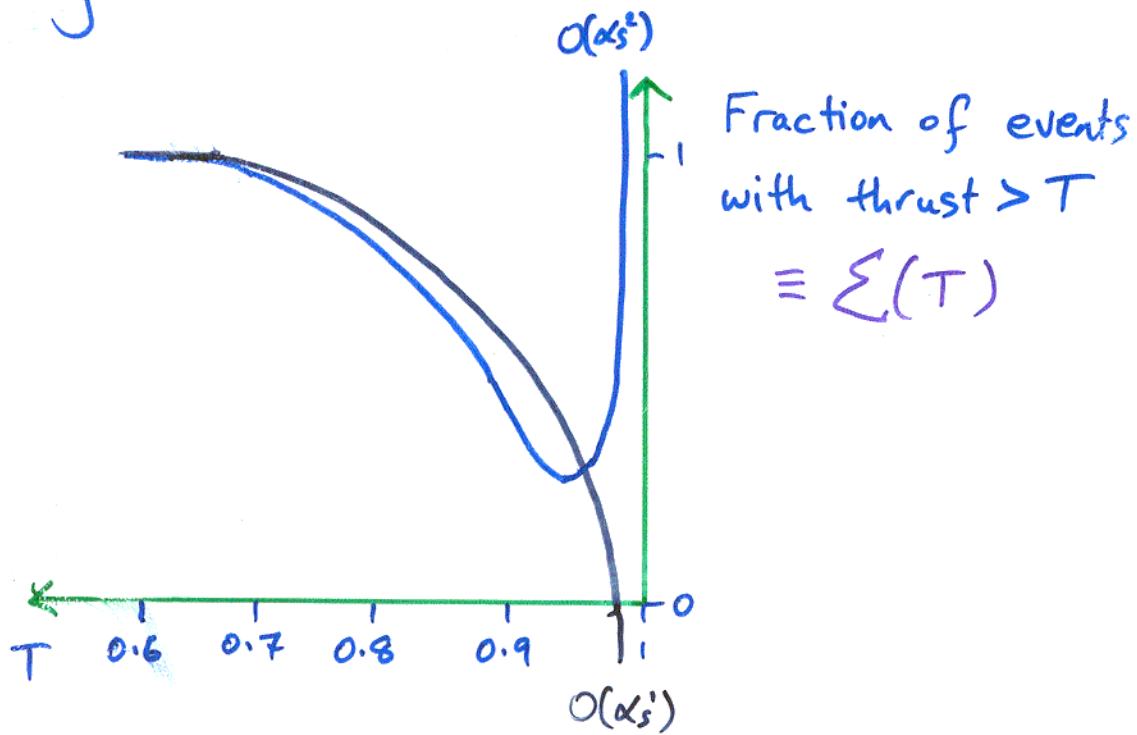
(leading log easy: Sudakov + running coupling ( $\kappa_s$ )

next-to-leading: hard collinear  
exact kinematics )

NLLA is NLO( $\kappa_s$ )  $\Rightarrow$  improved  $\mu$  dependence  
must match with exact NLO

## Event Shapes in $e^+e^-$

- 2 jet eg thrust



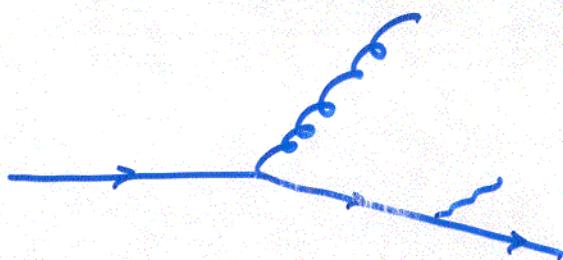
Finite order perturbation theory behaves unphysically as  $T \rightarrow 1$

$$\Sigma(T) = 1 - 2 C_F \left(\frac{\alpha_s}{2\pi}\right) \ln^2(1-T) + 2 C_F^2 \left(\frac{\alpha_s}{2\pi}\right)^2 \ln^4(1-T) + \dots$$

$$+ 3 C_F \left(\frac{\alpha_s}{2\pi}\right) \ln(1-T) + \dots$$

+ :

## Non-perturbative corrections



Thrust  $\sim$  additive  $\Rightarrow$  distribution shifted by soft gluons  
by amount  $\sim \int_0^Q \frac{dk_t}{Q} \alpha_s(k_t)$

Finite in any finite order of perturbation theory  
but: a) not resumable ("renormalon ambiguity")  
b) ill-defined in all-order PT ("Landau pole")

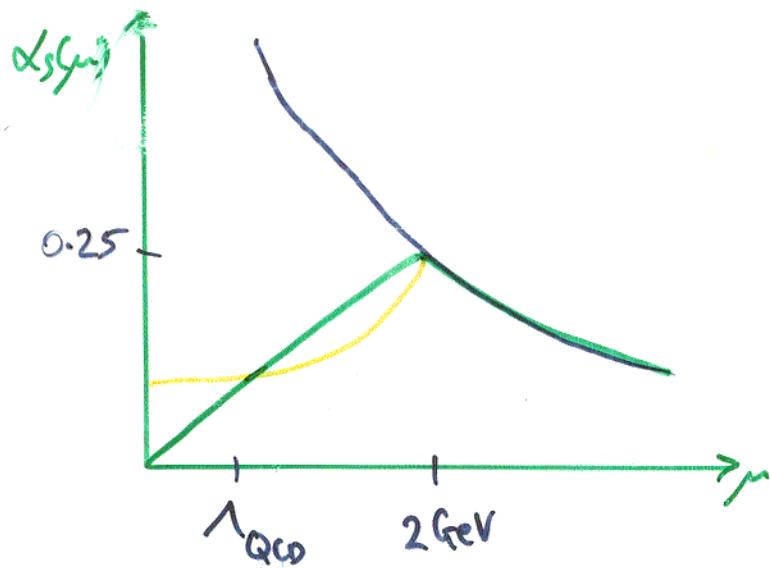
Solution:

universal non-perturbative  
corrections to  $\alpha_s$  at  
small scales

Webber 1994

Dokshitzer & Webber 1995

Marchesini, Dokshitzer & Webber 1996  
:



All event shapes sensitive  
to same moment of  $\alpha_s$

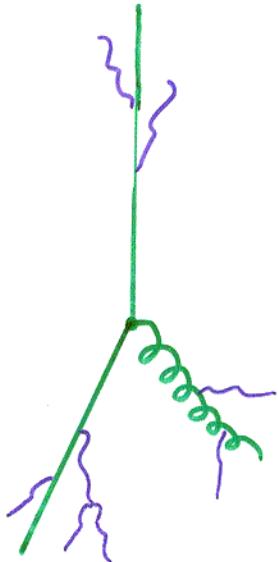
$$\alpha_o = \frac{1}{\mu_{IR}} \int_0^{\mu_{IR}} d\mu \alpha_s(\mu)$$

$\Rightarrow$  universal non-perturbative  
parameter

$\Rightarrow$  sideways shift of thrust distribution

## Event Shapes in $e^+e^-$

- 3 jet eg thrust-minor Banfi, Dokshitzer, Marchenini & Zanderighi  
2000



$$T_{\text{minor}} \sim \frac{1}{Q} \sum |p_{t,\text{out}}|$$

total  $p_t$  out of thrust plane

Much more complicated - colour structure  
- kinematics (recoils)

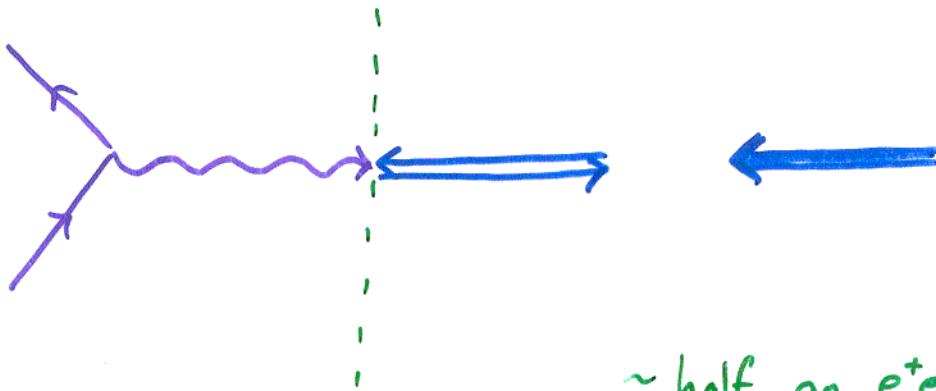
→ NP effects distort PT distribution

(but same  $\chi_0$  fits data  $\Rightarrow$  universal in  $e^+e^-$ )

## Event Shapes in DIS

Problem: incoming partons  $\rightarrow$  colinear singularities  
must factorize into universal pdf's  
 $\Rightarrow$  must not be sensitive to hadrons in  
remnant direction

Solution: look at part of event  
eg current hemisphere in Breit frame

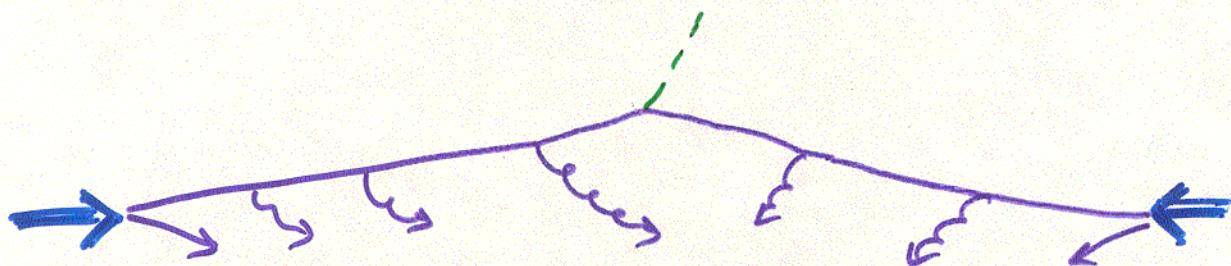


$\sim$  half an  $e^+e^-$  event  
at  $S_{ee} = Q^2_{\text{vis}}$

$\rightarrow$  analogues of all  $e^+e^-$  2jet event shapes  
 $\Rightarrow$   $\propto$  universal in quark-initiated processes

## Event Shapes in hadron-hadron?

- ~ jet shapes ("4-jet" non global event shape)
- ~ colour coherence studies ("3 jet" non global event shape)  
in W+jet
- ~ W p<sub>T</sub> distribution ("2 jet" event shape)



NLLA +  $O(\alpha_s^2)$  PT available

Non-perturbative shift comes from

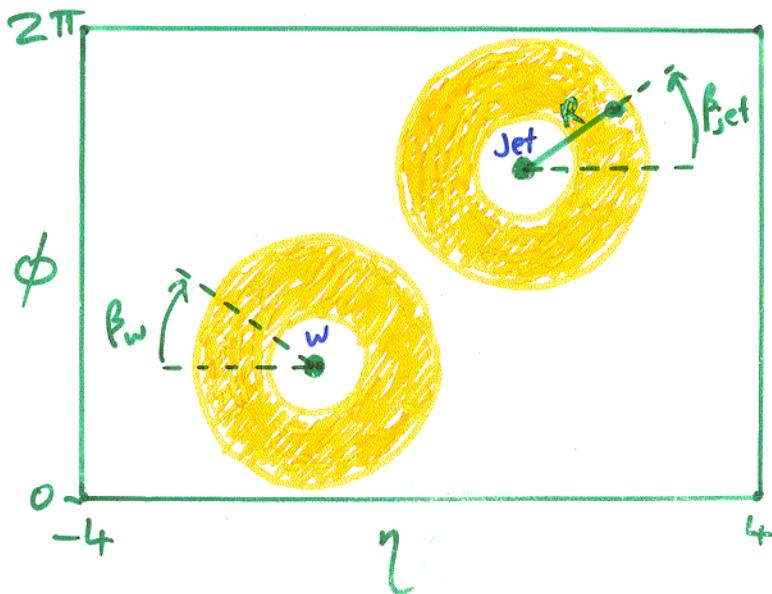
NP gluon corrections  $\sim \ln \frac{S}{M^2}$

+

"intrinsic" trans mom  $\sim$  constant

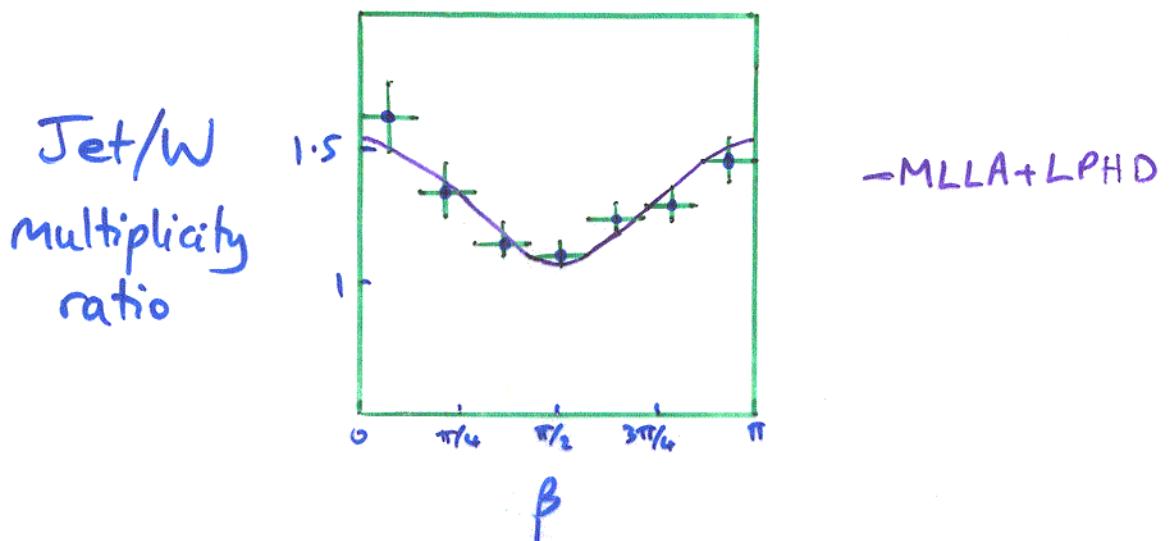
$\Rightarrow$  can't separate at fixed  $\sqrt{S}$ .

# Colour Coherence in W+jet - DΦ 1999



Jet side  $\rightarrow$  radiation prefers to be in plane

W side  $\rightarrow$  radiation more uniform

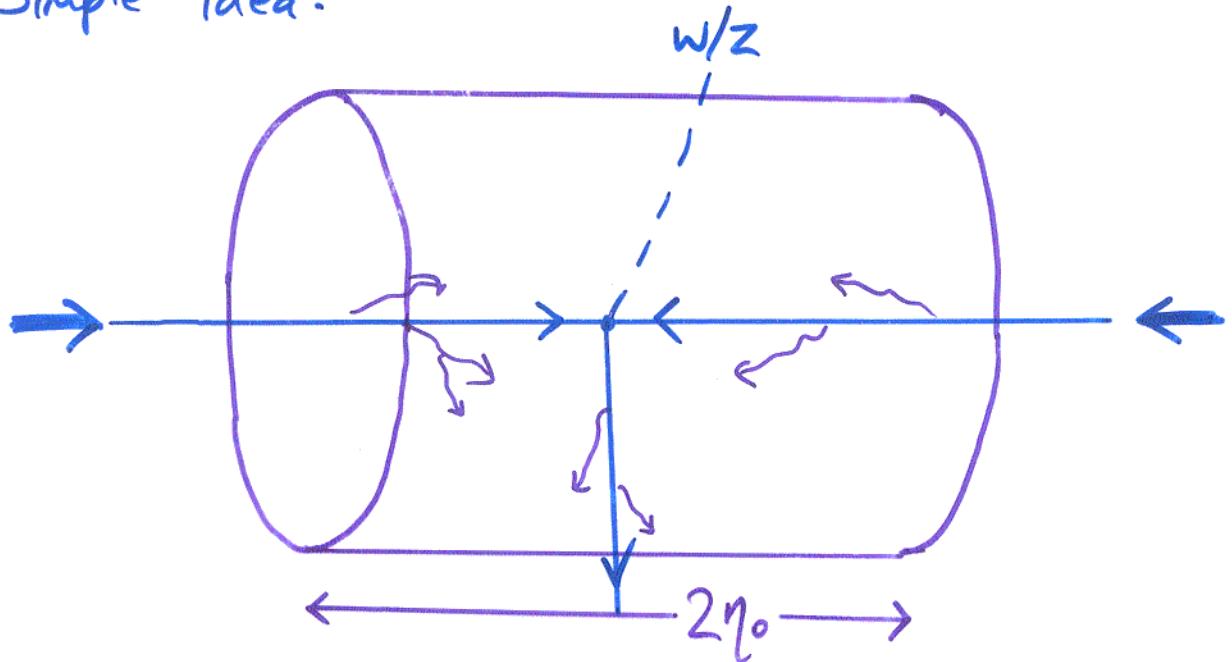


Analytical prediction  $\sim$  perfect shape  
but  $\sim$  factor 2 in normalization!

## Out-of-plane QCD Radiation in Hadronic $Z^0$ Production

- Banfi, Marchesini, Smye & Zanderighi 2001

Simple idea:



$W/Z + 2$  hadrons define plane  $\Rightarrow$  no need for jet algorithms

$$K_{out} \equiv \sum_{|\eta| < \eta_0} |\vec{p}_{b,out}|$$

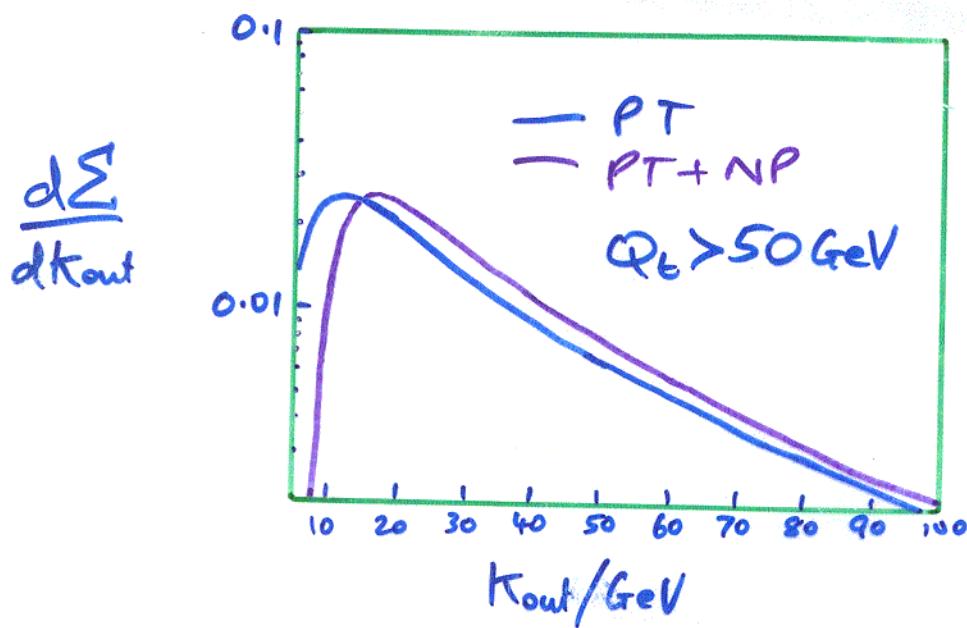
$$\sum(Q_{cut}, K_{cut}) \equiv \frac{\sigma(Q_t > Q_{cut}, K_{out} < K_{cut})}{\sigma(Q_t > Q_{cut})}$$

But: sensitive to initial state singularities  
 $\Rightarrow$  no factorization

$\Rightarrow$  introduce rapidity cut  $\eta_0$

Some features:

- independent of "intrinsic"  $R_E$
- very similar to Tminor (cf recoils)
- perturbative results independent of  $\eta_0$   
(for  $K_{out} \gtrsim M_{w/Z} e^{-\eta_0} \sim 10 \text{ GeV}$ )
- non perturbative corrections from three sources:
  - final state gluons ( $\eta_0$ -independent distortion)
  - initial state gluons ( $\eta_0$ -dependent shift)
  - underlying event ( $\eta_0$ -dependent, process-indep. shift)



- needs to be matched with W+2jet NLO
- needs a lot more phenomenological study  
but....

How to calculate non-global logs?

New, non-factorizing dynamics  $\Rightarrow$  challenge!

Approximate evolution equations for "buffer region"  
around region of interest - Banfi, Marchesini & Snyder

## How to control non-global logs?

1. Simultaneously measure global event shape outside region of interest - Berger, Kucs & Sterman 2003  
- Dokshitzer & Marchenini 2003
  - factorization ?
  - experimentally measurable ?
2. Cluster event using  $k_t$  jet algorithm  
measure minijet  $p_T$  rather than hadrons - H1  
- Zeus  
- Appleby & MHS 2002

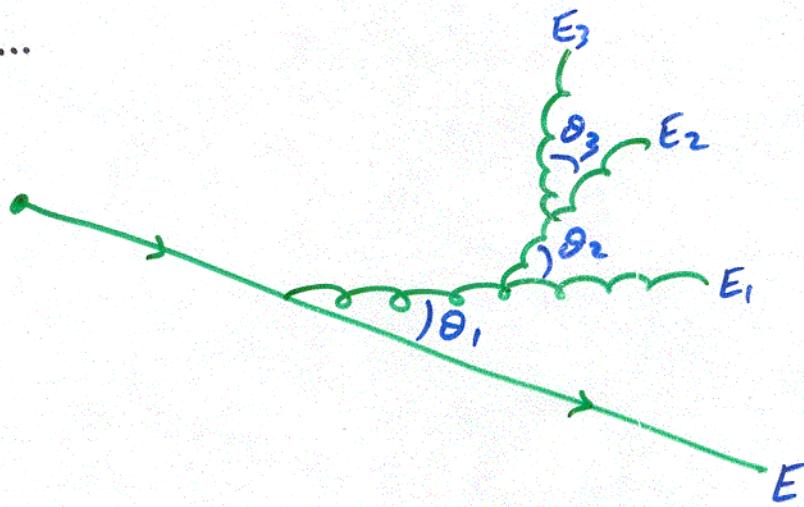


→ factor 2-3 reduction in non-global logs  
(smaller detector corrections  
smaller non-perturbative corrections)

## Non-global Logarithms - Dasgupta & Salam 2022

After >10 yrs study, NLLA thought to be well-understood.

But, ...

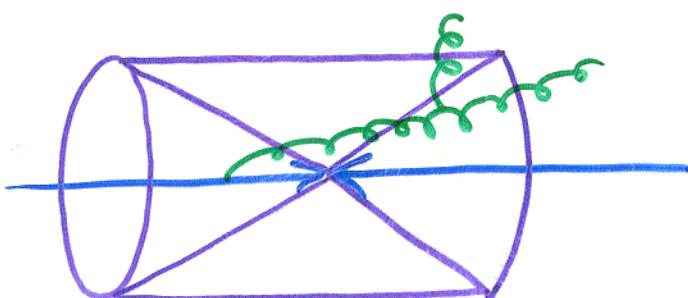


Strongly-ordered energies:  $E \gg E_1 \gg E_2 \gg E_3 \dots$

Opening angles similar:  $\theta_1 \sim \theta_2 \sim \theta_3 \dots$

Guaranteed to cancel in global event shapes

but non-global?

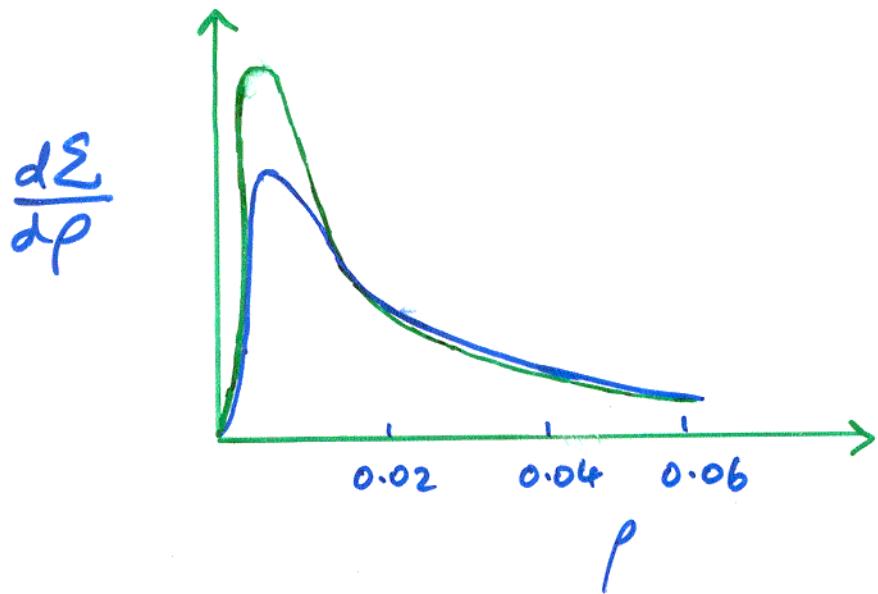


$p_T$  inside region can be increased by hard gluons outside it.

$\Rightarrow$  next-to-leading log

$\Rightarrow$  non-factorizing (resumable?)

Impact estimated numerically (Dasgupta & Salam)



e.g. hemisphere  
mass in DIS

$$\rho \equiv \frac{m^2}{Q^2}$$

upto ~30% correction for event shapes

> factor of 2 for "gaps between jets"

## Summary

- Hard/soft interface is hottest topic in QCD
- Direct impact on non-QCD studies
  - W mass
  - jet resolution
  - background calculation reliability
- If Tevatron is to become post-LEP QCD laboratory,  
must get to grips with event shapes
- Out of plane radiation in W/Z + jet first attempt  
at 3-jet-like event shape in hadron-hadron
- Needs detailed phenomenological study
- Needs detailed experimental study
- Possible to define global event shapes for  
hadron-hadron collisions?
- Possible to reduce impact of non-global logs in  
hadron-hadron collisions?